OBSERVATIONS ON THE MAGNITUDE-FREQUENCY DISTRIBUTION OF EARTH-CROSSING ASTEROIDS

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During the past decade, discovery of Earth-crossing asteroids has continued at the pace of several per year; the total number of known Earth crossers reached 70 as of September, 1986. These objects comprise 36 numbered and 34 unnumbered asteroids, 11 of which are lost; 6 are Atens, 41 are Apollos, 22 are Earth-crossing Amors, and one of the Earth crossers has a present perihelion distance of greater than 1.3 AU. The sample of discovered Earth crossers has become large enough to provide a fairly strong statistical basis for calculation of mean probabilities of asteroid collision with the Earth, the Moon, and Venus. It is also now large enough to begin to address the more difficult question of the magnitude-frequency distribution and size distribution of the Earth-crossing asteroids.

Absolute V magnitude, H, has been derived from reported magnitudes for each Earth crosser on the basis of a standard algorithm that utilizes a physically realistic phase function (Minor Planet Circular 10193). On average, $H = V(1,0) - 0.3$, where $V(1,0)$ is the absolute magnitude based on a linear phase function. Fairly reliable observations of magnitude are available for most numbered Earth crossers, but observations are sparse for unnumbered objects and commonly consist only of visual estimates of B made from photographic plates. In the latter case, the derived value of H is calculated only to the nearest half magnitude.

The derived values of H range from 12.88 for (1627) Ivar to 21.6 for the Palomar-Leiden object 6344, which is the faintest and smallest asteroid discovered. The absolute magnitude of Ivar is close to the magnitude threshold for completeness of discovery of asteroids in the inner part of the main asteroid belt. It is possible that one or two more Earth crossers as bright or brighter than Ivar remain to be discovered, but it is unlikely that there are as many as ten. Completeness of discovery drops with increasing magnitude. Shoemaker et al. (1979) estimated the population of Earth crossers to $V(1,0) = 18$ (equivalent to $H = 17.7$) at ~1300; the observed number at $H = 17.7$ is 50, which corresponds to an estimated completeness of discovery of about 4%.

If we adopt the estimate of 1300 for the total number of Earth crossers brighter than $H = 17.7$ and assume that the number brighter than $H = 12.88$ does not exceed 3 Earth crossers, a plausible magnitude-frequency distribution for the population to $H = 17.7$ can be represented approximately by

$$N = 3.17\ e^{-1.28\ (13-H)}, \qquad (1)$$

where N is the cumulative frequency (fig. 1). This distribution corresponds to a monotonically decreasing completeness of discovery with increasing magnitude above 13.2, which is expected from circumstances of asteroid discovery. The distribution represented by eq. (1) is much steeper than the estimated average magnitude-frequency distribution of main belt asteroids,

which can be represented approximately by

$$N \propto e^{-0.9(-H)}. \tag{2}$$

To the extent that Earth-crossing asteroids are derived as collision fragments from main belt asteroids, the size and magnitude distribution of Earth crossers can be expected to be steeper than those of main belt asteroids. Most collision fragments that become Earth-crossing objects probably are displaced in orbital element phase space into secular resonances by impulses of the order of hundreds of meters per second. Small collision fragments tend to receive larger impulses than large fragments, and small fragments probably are delivered preferentially to secular resonances and ultimately to Earth-crossing orbits.

The exponent (size index) of the cumulative size-frequency distribution of the impactors that produced the post-mare lunar craters $\geqslant$10 km diameter has been estimated at -1.62 (Shoemaker, 1983). A power function of the diameter with this exponent corresponds to an exponential magnitude-frequency distribution for the impacting objects of the form

$$N \propto e^{\frac{-1.62}{5 \log e}(-H)} = e^{-0.75(-H)}, \tag{3}$$

under the condition that the range of albedo is similar for objects of different sizes. This derived magnitude distribution for post-mare impactors is much flatter than eq. (1) and also is flatter than the magnitude distribution of discovered Earth-crossing asteroids in the range $13 \leqslant H \leqslant 16$ (fig. 1). If 1300 is adopted as the cumulative number to $H = 17.7$, then the number of objects predicted by (3) at $H = 13$ is 30 times higher than the number observed. Conversely, if discovery of Earth crossers were considered complete at $H = 13$, then fewer objects than have already been discovered to $H = 17.7$ would be predicted by (3). From the ratio of the frequency of discovery of new Earth-crossing asteroids to the frequency of accidental recovery of those already known, it is certain that the number remaining to be found to $H = 17.7$ is many times greater than the number now known. If it is assumed that most 20-km-diameter, post-mare impact craters have been produced by asteroid impact, then the difference in exponent between (1) and (3) suggests that no more than 1/3 of the craters with diameters $\geqslant$50 km were formed by Earth-crossing asteroids. The large lunar craters probably have been formed chiefly by impact of comets.

References

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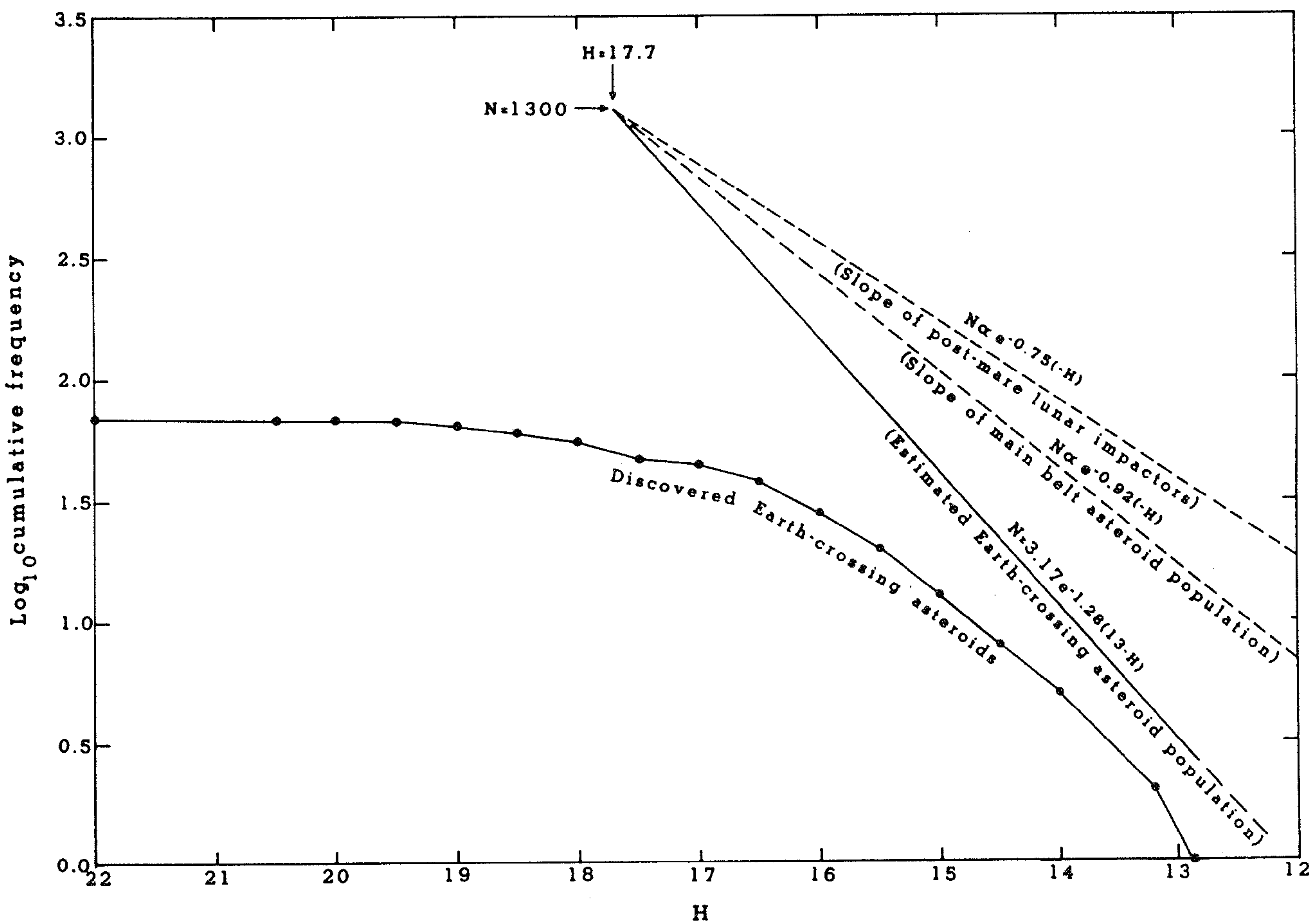

Figure 1. Magnitude-frequency distribution of Earth-crossing asteroids.